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A HF PULSED TRANSMITTER FOR AN EXPERIMENTAL CROSS-CORRELATION RADAR SYSTEM

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F. E. Boyd and R. G. Cumings

Radar Techniques Branch
Radar Division

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ABSTRACT

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A 40-kw peak power, radar research transmitter for unconventional operation on 26.6 Mc with 1/8 duty factor is described. Methods of obtaining excellent frequency stability and constant starting phase of the rf pulse are detailed. Circuits for step frequency modulation, pulse dividing, and monitoring are included. Operation of tetrode and pentode power tubes in pulse service is discussed; and also methods of generation and maintaining a desired rf pulse shape.

PROBLEM STATUS

This report describes a pulsed radar transmitter and closely associated equipment which is part of a research type radar. Work is continuing and subsequent reports will describe the antenna, duplexer, receiving-detection system, indicators, and system capabilities.

AUTHORIZATION

NRL Problem R02-23
Project NR 412-000
Subproject NR 412-007

Manuscript submitted September 27, 1956

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A HF PULSED TRANSMITTER FOR AN EXPERIMENTAL CROSS-CORRELATION RADAR SYSTEM

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INTRODUCTION

Very little has been published on hf pulse transmitters. The basis for general design is a combination of hf communication transmitter techniques and pulse radar transmitter practice. This procedure is necessary if maximum efficiency and low cost are to result. Several unique problems which require special consideration are (a) oscillator starting phase characteristics, (b) electron tube operating points, and (c) pulse shaping in a class C amplifier. The oscillator starting phase characteristics are important in a coherent radar. The requirement that every rf pulse must have short term frequency identity and constant starting phase dictated the use of some form of pulsed master oscillator. The stages following a free running oscillator could be plate modulated in synchronism with this oscillator but the method would be more complicated and require large and costly modulators. In view of this situation, a pulsed master oscillator was chosen, and consequently the following power stages of the transmitter chain are operated class C with sufficient fixed bias to cut off between pulses. Tetrodes are used in the buffer and final stages because of their realizable large power gains. The particular system requires 26.6-Mc operation, a 1/8 duty factor, and a 250-microsecond pulse length.

EXCITERS AND MODULATORS

Exciter Systems

Radar pulse transmitters fall generally into two categories, those with power oscillators and those with master oscillator-power amplifiers. Several power oscillators were investigated for suitability to this problem. The required pulse length of 250 microseconds with a duty factor of 1/8 necessitated the use of an elaborate modulator rather than the pulse transformer normally used with short pulse systems.

Figure 1 shows the block diagram of one form of a power oscillator transmitter. In this system the grid was modulated in preference to the plate because of the high pulse power that would be required in plate modulation. Inasmuch as the tube elements that affect frequency stability also handle considerable power, the best obtainable frequency stability of this system was unacceptable for the problem at hand. It was found that distortion due to heating of the oscillator plates during the pulse duration actually produced considerable unacceptable frequency modulation.

It was known that the alternative system of master oscillator-power amplifier, though requiring more equipment, has the advantage of versatility in addition to frequency stability. A master oscillator-power amplifier system can be operated on one frequency straight through from the oscillator to final amplifier; however, when several amplifiers are needed to obtain the required power level, the chance of self oscillation is considerably reduced by resorting to frequency doubling in all or in alternate stages.

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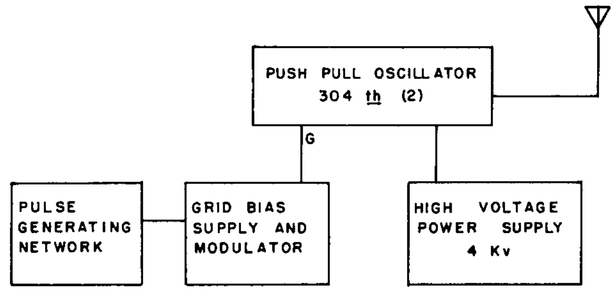

Fig. 1 - Grid pulsed power-oscillator transmitter

The master oscillator-power amplifier exciter system which was adapted to driving the higher power amplifiers is shown by block diagram in Fig. 2. The labels on this diagram are self-explanatory; however, attention is called to the keying-pulse input and the fm input, which provides the transmitter with step frequency capabilities.

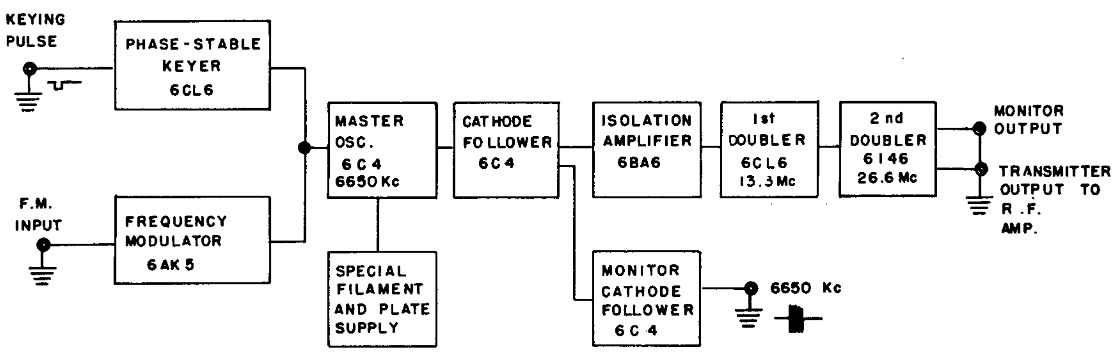

Fig. 2 - Transmitter exciter

Pulsed Master Oscillators

Several oscillator circuits including a Clapp and a conventional Colpitts oscillator were investigated. A screen pulsed electron coupled oscillator (Fig. 3) exhibited the same performance connected either as a Colpitts or a Clapp oscillator. The frequency stability of this type of oscillator was found to be satisfactory for the problem requirements, but the starting phase was not sufficiently constant from pulse to pulse due to the slow build-up of oscillations.

To insure good frequency stability and constant starting phase, forced build-up of a frequency stable system was found to be necessary. A cathode keyer connected to the oscillator tank as shown in Fig. 4 accomplishes the forced built-up; isolation of the frequency determining elements improves the frequency stability. The cathode keyer in this figure is normally conducting through the tank coil at a level determined by the 10K resistor, thereby preventing oscillation by loading. Application of a negative pulse to the grid of the keyer input cuts off the keyer tube current, and at the same time stored energy aids the build-up of the oscillator through application of the controlled pulse in the cathode circuit. Figure 4 also shows circuit details of the monitor and first isolation amplifier.

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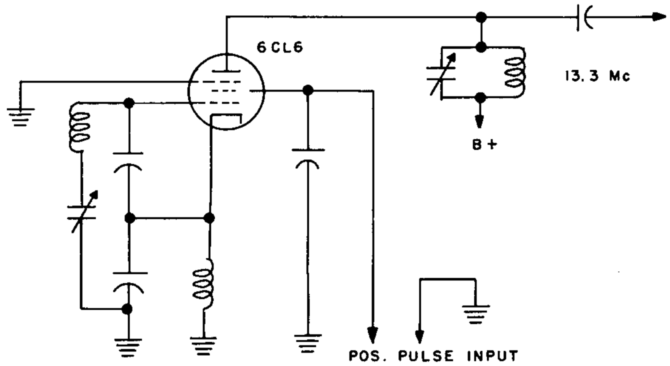

Fig. 3 - Screen triggered oscillator

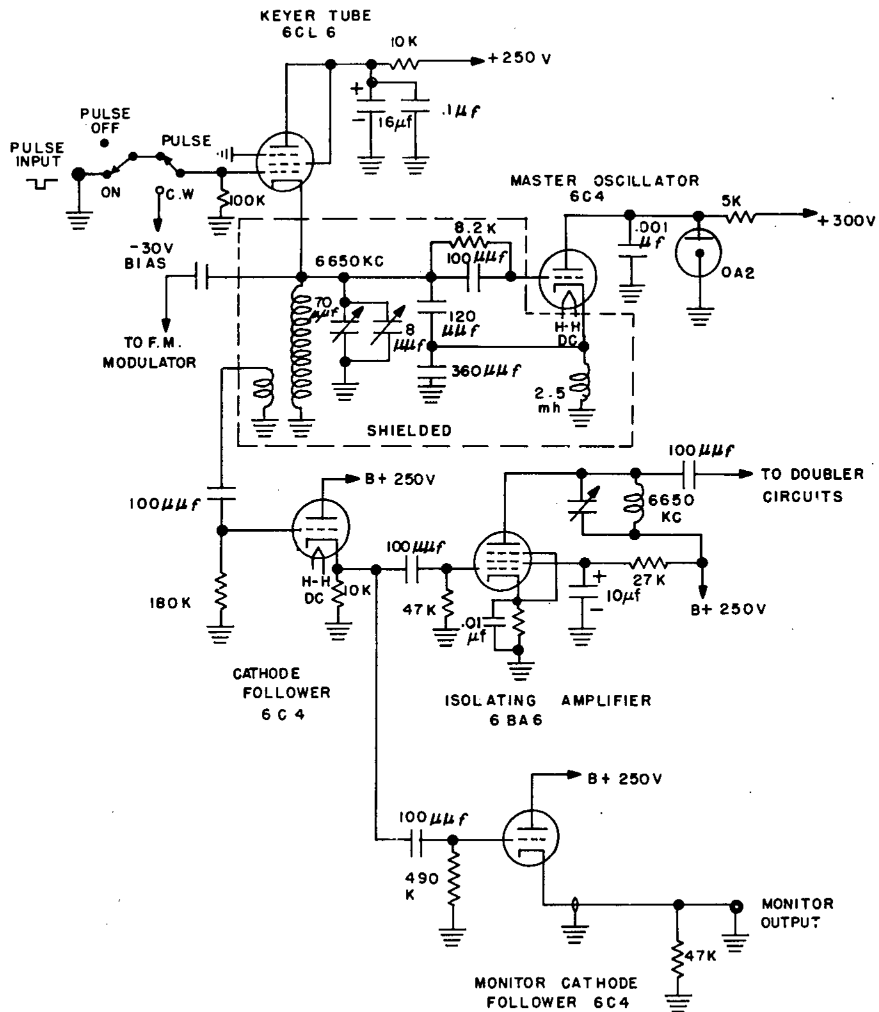

Fig. 4 - Pulsed master oscillator

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Figures 5 and 6 show the waveforms of the circuit's pulse performance. Figure 6 is an expansion of the performance shown in Fig. 5 and represents the superposition of many pulses. To eliminate extraneous field difficulties and to reduce frequency drift due to that caused by temperature changes, critical components of the oscillator were enclosed in a separate shield (Fig. 7). The effects of incidental modulation from all sources was thoroughly examined, because such modulation of the oscillator would be detrimental. It was necessary to eliminate the small amount of 60-cycle modulation that would be caused by ac filament operation by operating the filaments of the oscillator and oscillator output follower on dc.

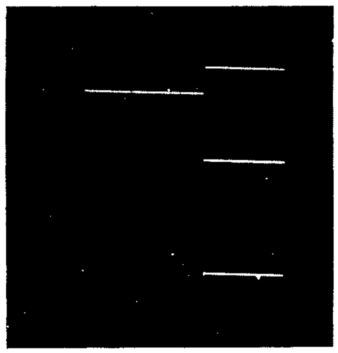

Fig. 5 - Exciter waveforms

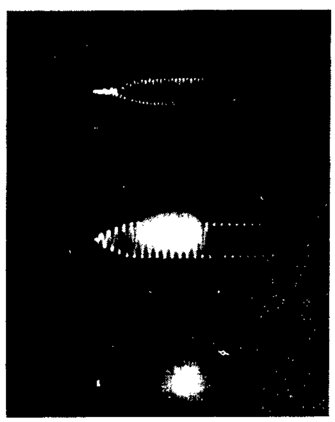

Fig. 6 - Exciter waveforms expanded

Loading effects on oscillator stability were greatly reduced by coupling the oscillator output through a cathode follower and an isolating amplifier (Fig. 4). A 6BA6 was chosen as an isolating amplifier because of its well-screened grid and low current drain. An isolating cathode follower was also used to provide a test point to monitor oscillator operation.

Considerable attention was given to the proper time constants of decoupling networks. Whenever a dc component is present in the circuit, alone or in addition to radio frequency, the decoupling network was designed to effectively filter out the dc pulse. A time constant equal to 200 times the pulse length was generally used. Additional filtering, specifically

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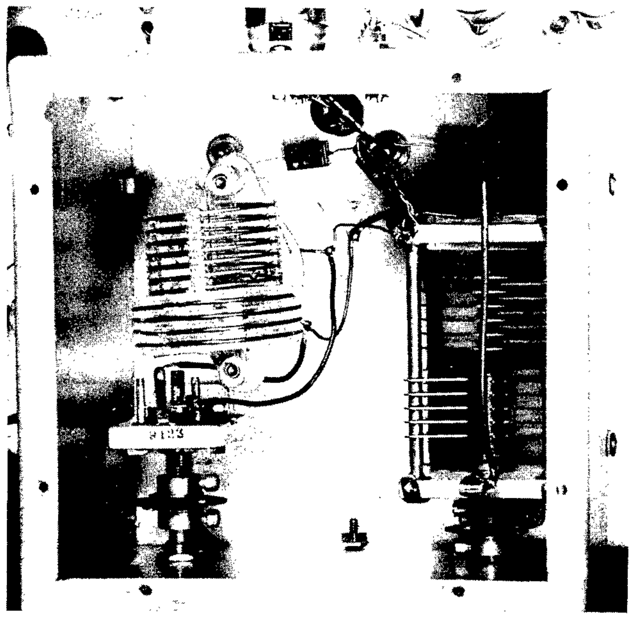

Fig. 7 - Oscillator tank compartment

for the radio frequency, was used where customary practice dictated. The screen circuits of the doublers were found to be important in this respect. They provide amplitude modulation in an unwanted manner when inadequate bypass capacity is used.

Doubler Circuits

The first and second doublers are the conventional class C type, modified for pulse use as shown in Fig. 8. The first doubler, a 6CL6, is tuned conventionally to 13. 3 Mc and has more than ample power capacity to drive the second doubler, a 6146. Sufficient reserve peak power drive is available in this arrangement if so desired.

The second doubler output is at the final frequency of 26. 6 Mc. The power output is adjustable from 1 watt to 35 watts by varying the screen voltage. The output coil is coupled by a fixed link and tuned to match a 93-ohm line. The two unwanted subharmonics, 6650 kc and 13. 3 Mc are also present in the output, hence an acceptance filter (Fig. 9) is placed in the output to pass only 26. 6 Mc. (The design of this filter is detailed in another report. *) By this means 6650 kc and 13. 3 Mc are rejected in the order of 70 db or greater. Likewise the unwanted second and third harmonics of 26. 6 Mc are also rejected by a similar order of magnitude. The final power amplifier re-creates some measure of the unwanted harmonics, and they are rejected again by filtering prior to radiation.

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*"An Investigation of Fundamental Circuit Factors Which Influence Spurious Response and the Generation of Spurious Radiation," Final report, Contract No. AF 33(600)-27091, The Electro-Mechanics Company, December 6, 1955

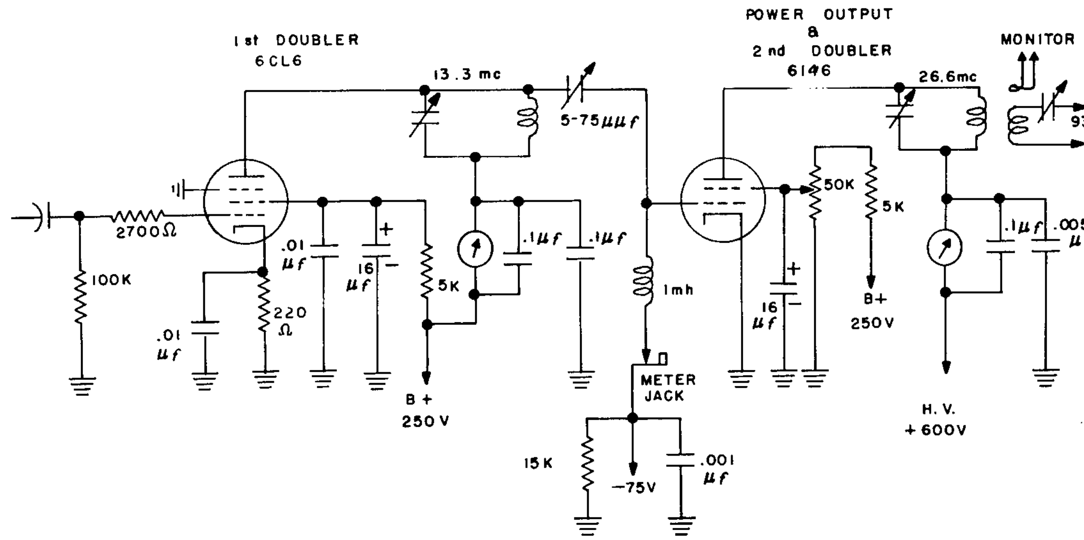

Fig. 8 - Doubler circuit

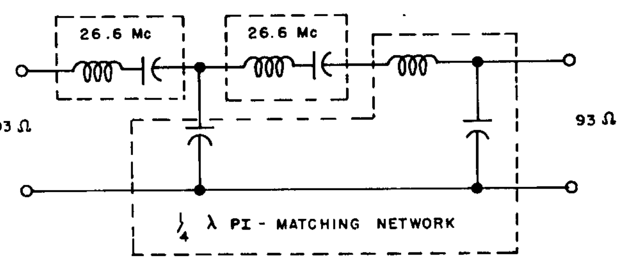

Fig. 9 - Output acceptance filter

Frequency Modulator

Orderly shifting of the frequency of the transmitter a known small amount by a selected program was considered a necessary research tool in operation of associated equipment with the subject transmitter; hence a means of linear shift was provided up to ±60 kc. Figure 10 shows the frequency shift circuitry connected to the oscillator tank circuit. It is seen that a vacuum tube is used as a variable resistance in series with a capacitor across the oscillator tank circuit. This tube is biased to the middle of its linear range and is dc coupled to the frequency shifting source. Figure 11 shows the performance curve of frequency deviation versus grid input.

PULSE DIVIDER

The research radar transmitter was designed to have a nominal repetition rate of 500 pps, with lower rates available. For this purpose, pulse divider circuitry was arranged to deliver keying pulses from any one of several sources at the original or at a time divided repetition rate. Figure 12 shows a block diagram of a satisfactory system. After a selection

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of one of three inputs, the pulse is inverted, differentiated, and used to trigger the first binary if division of the repetition rate is desired. Figures 13 and 14 show respectively the typical binary circuitry and waveforms associated with Fig. 12. The first binary triggers on the trailing edge of the inverted pulse. After selection of the proper binary for the degree of division desired, the binary output is fed to a gate generator which produces a pulse long enough to gate the next succeeding pulse from the original source. The gate pulse then is fed to a special gate circuit, called a "unipulse gate," which accepts the gate pulse and the inverted T pulse simultaneously but passes only the T pulse to the output circuit. Thus, the divided output contains pulses with the accuracy of the input source and eliminates the problem of regenerating and matching a pulse.

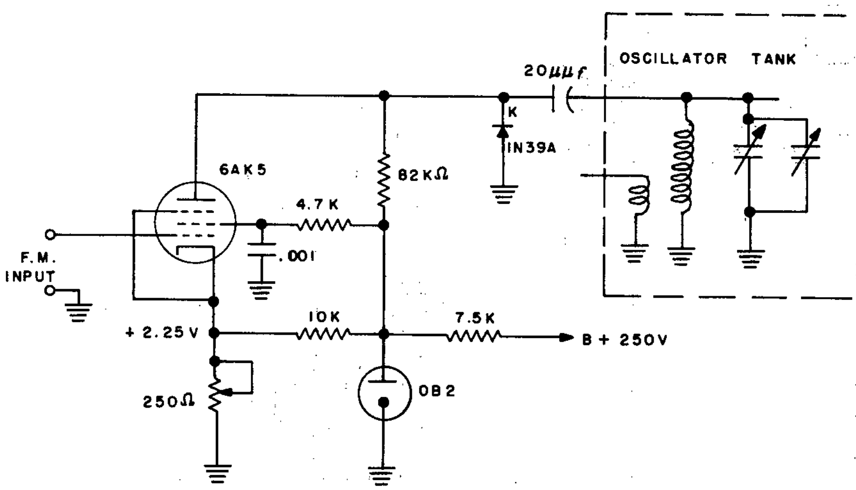

Fig. 10 - Frequency shift (fm) modulator

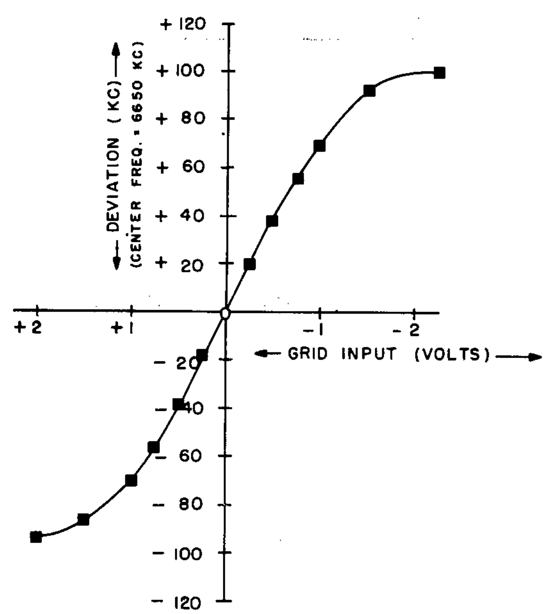

Fig. 11 - Deviation curve for the (fm) modulator

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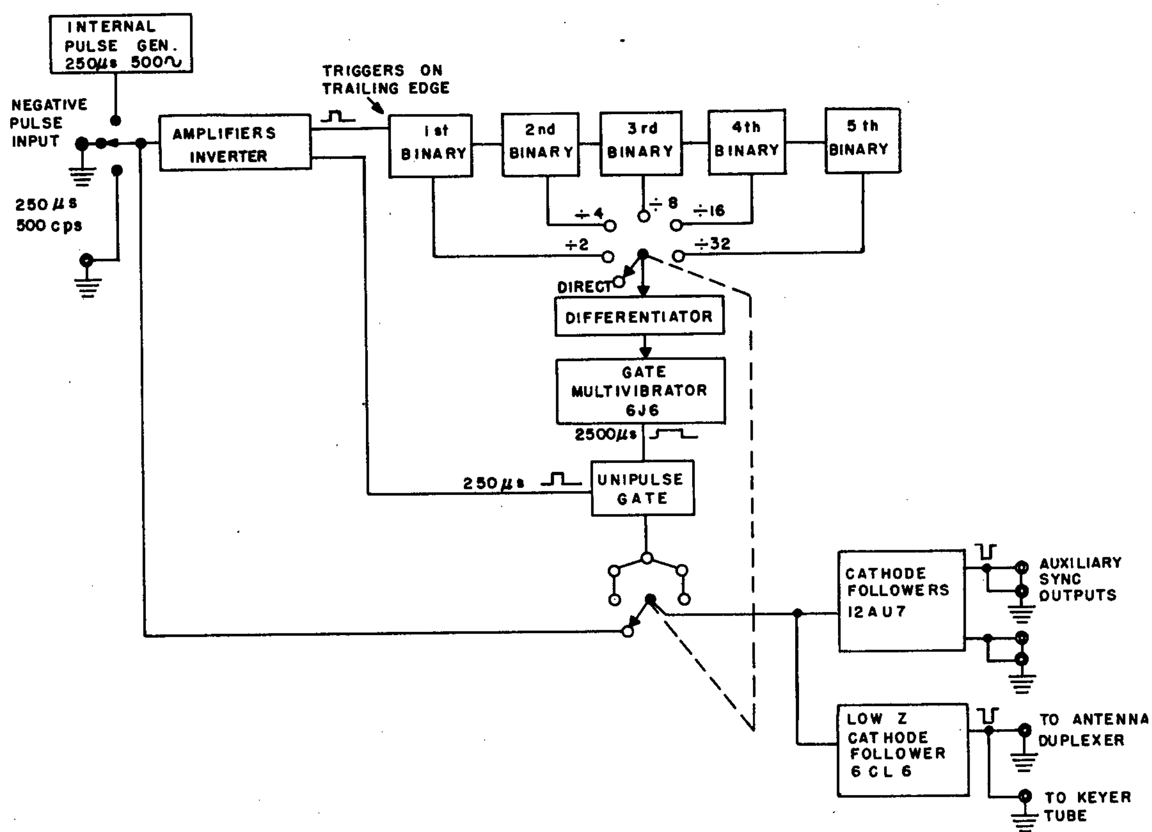

Fig. 12 - Pulse divider for the transmitter exciter

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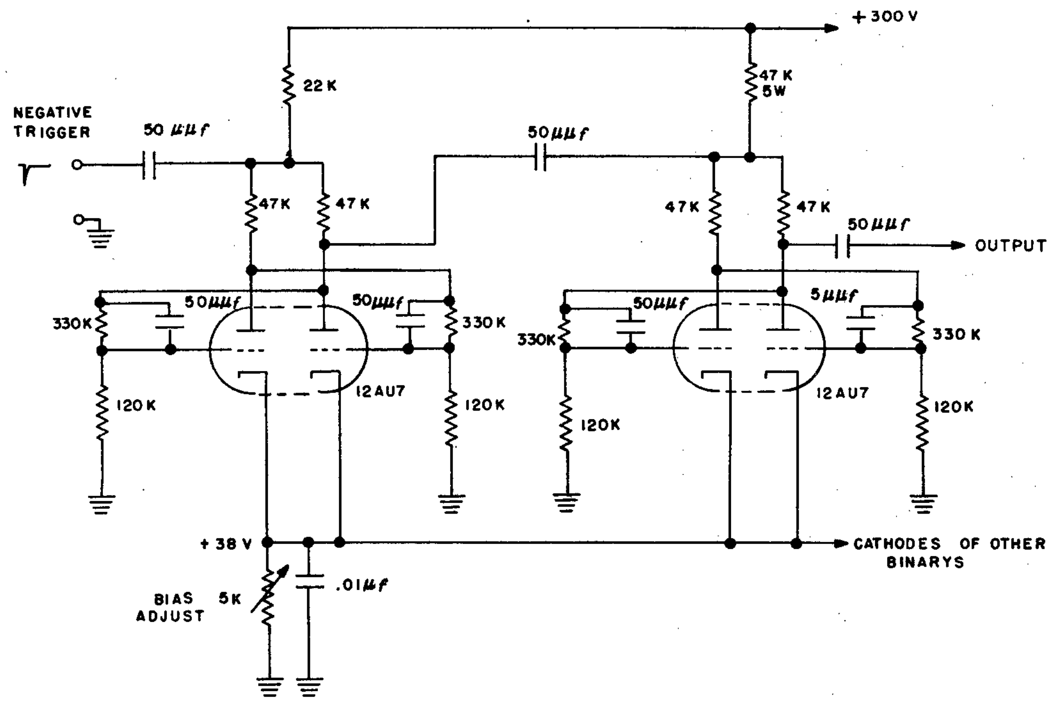

Fig. 13 - Binary circuit

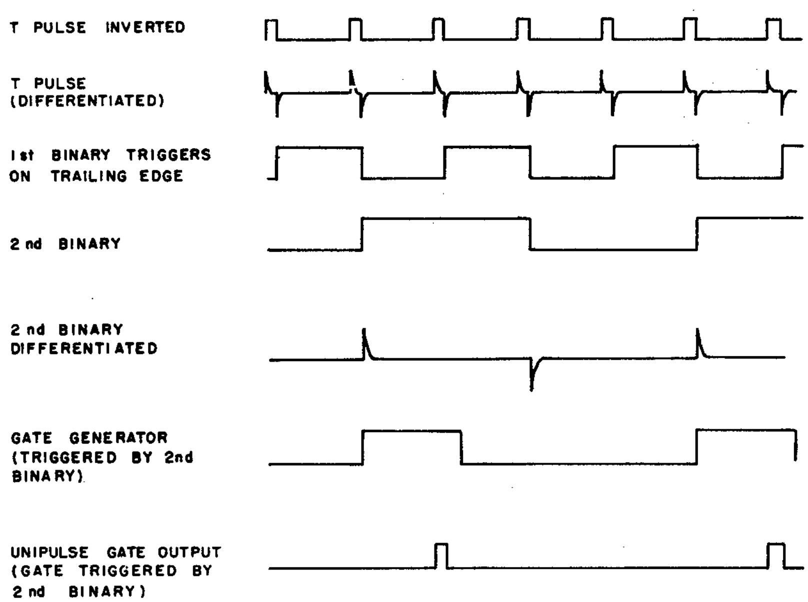

Fig. 14 - Waveforms in the pulse divider. The inverted T pulse is normally 250 microseconds, and the gate pulse is 2,300 microseconds.

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The unipulse gate (Fig. 15) is a circuit using a dual control tube incorporating a dc coupled cathode follower in conjunction with an amplifier circuit. The gate multivibrator feeds the first grid with a pulse of sufficient amplitude to overcome the fixed bias. The first grid and the screen operate as a cathode follower producing the gate pulse across the 4.7K upper section of the cathode resistor, biasing the third grid just below cutoff. A positive pulse input at the third grid causes the plate to conduct, causing an output across the 6800-ohm resistor containing only the gated pulse and not the gate pulse itself. The output is then fed through cathode followers to the transmitter keyer tube, synchronizing circuits for observing oscilloscopes, and the antenna duplexer system. The antenna duplexer and keyer tube operate off the same independent low impedance cathode follower to make certain that the duplexer receives a pulse when the transmitter operates, regardless of accidental shorts in the synchronizing circuits of auxiliary equipment.

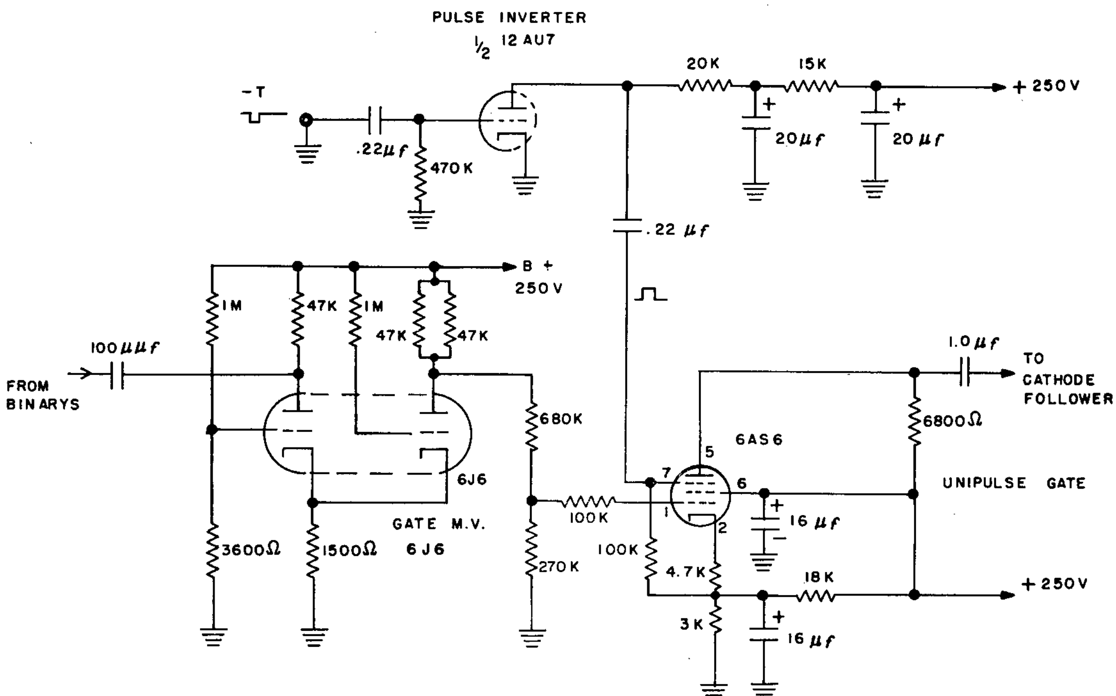

Fig. 15 - Unipulse gate

POWER AMPLIFIER CONSIDERATIONS

A brief review of available power amplifier tube ratings will quickly reveal that the tubes normally used in radar transmitters are not suitable in the subject application because of their low plate dissipation ratings in combination with the high duty factor (1/8) required. It was therefore necessary to use tubes primarily designed for communications transmitters. Since the data for pulse operation of these tubes is not available in the tube handbooks, it was necessary to extrapolate from the data given for cw operation. It will be observed that the plate dissipation and available filament emission of most power tubes is so proportioned that when the duty factor is equal to or greater than 1/12, assuming 80-percent efficiency, the maximum power is limited by the allowable

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plate dissipation. Since the most severe duty factor in the subject case is greater than 1/12, a choice of the operating condition is available ranging from the maximum emission case to the maximum plate voltage case.

The maximum dc plate input during the pulse may be quickly computed in the case limited by plate dissipation as follows:

$$\text{Max dc input during pulse} = \frac{\text{Plate dissipation}}{\text{Duty factor} \quad (1 - \text{Eff.})} \tag{1}$$

Corresponding bias voltages and screen voltages and currents may be approximated by use of the conversion factors for power tubes published in the RCA and other tube handbooks. As an example, the operating conditions for a type 4-250A tube operated at maximum emission are computed below:

Step 1

Max plate dissipation = 0. 25 kw

Applying expression (1):

$$\text{Max dc input during pulse} = \frac{0.25}{1/8 \times (1 - 0.8)} = 10 \text{ kw}$$

Step 2

Filament power consumption = 5 v × 14. 5 amp = 72. 5 w

Peak fil emission at 80 ma per watt of fil power =

72. 5 × 0. 08 = 5. 8 amp

For most rf amplifiers, the average plate current during the rf pulse is between 1/4 and 1/5 of the peak current. Assuming the former figure for safety, one arrives at an average plate current during pulse of 5. 8 amp × 1/4 = 1. 45 amp. Since the duty factor is 1/8, the dc plate current is 1. 45 × 1/8 = 0. 181 amp.

Step 3

$$\text{DC plate voltage} = \frac{\text{Max dc input power during pulse}}{\text{Avg plate current during pulse}}$$

$$= \frac{10 \text{ kw}}{1.45 \text{ amp}} = 6.9 \text{ kv}$$

Step 4

Using the manufacturer's data for operation of the tube at 4 kv, the voltage conversion factor, F_e, becomes 6. 9 kv/4 kv = 1. 73. From a conversion factor chart: Screen supply voltage = 500 v × 1. 73 = 865 v; DC screen current = 45 ma × F_i × d. f. = 45 × 2. 3 × 1/8 = 13 ma and Grid bias voltage = 225 v × 1. 73 = -378 v. The grid current is best determined experimentally. Additional operating conditions for the 4-250A are given in Table 1; conditions for the type 6146 and the 4-1000A tubes are also included in this table.

TABLE 1
Approximate Pulse Operating Conditions for Class C RF Amplifiers with a Duty Factor of 1/8

	Type 6146	Type 4-250A		Type 4-1000A	
DC Plate Voltage	1,500	6,900	10,000	10,300	15,000
DC Screen Voltage	320	865	1,250	860	1,200
DC Grid Voltage	-124	-378	-560	-346	-500
DC Plate Current (ma)	41	181	125	396	267
DC Screen Current (ma)	4	13	22	40	63
DC Grid Current (ma)	0.5	5.5	—	8	—
Peak Driving Power (watts)	—	~20	~20	~90	~90
Peak Power Output (watts)	385	8,000	8,000	25,600	25,600

PULSE SHAPING

In a radar transmitter of the long-pulse type it is not necessary, or even desirable, to have sharp leading and trailing edges on the pulse. A rise time and a fall time which are equal to 5 percent of the total pulse length will not reduce the power in the pulse a prohibitive amount. If this factor does become a consideration, then the pulse can be lengthened a slight amount to decrease the power loss. The chief advantage in limiting the rise time is the reduction of unnecessary side frequencies. This feature greatly alleviates the interference problem, especially since transmitters of the subject type may have considerable average power.

The design feature of the master oscillator, which was to insure stable starting phase, results in its output having a relatively rapid rise time. It is well known that class C amplifiers tend to make the rise time even more rapid. As a result, early trials of the system produced output pulses with rise times of the order of several microseconds and large amounts of overshoot. Overshoot is largely due to improper regulation of the power supplies, and this is readily eliminated.

Actual output pulse shaping by reduction of the rise and fall times has not been incorporated in the transmitter, although several methods of accomplishing the function have been considered. It appears likely that some form of amplitude modulation will suffice. Modulation of the final amplifier screen has considerable appeal as a method for controlling the rise and fall time, because it would require little power and remain independent of other factors controlling the operation of the transmitter.

TRANSMITTER ASSEMBLY

The complete transmitter, shown in Fig. 16 in block form, consists of the exciter and modulator (Fig. 2) followed by a pair of 6146 tubes in push-pull which drive the push-pull

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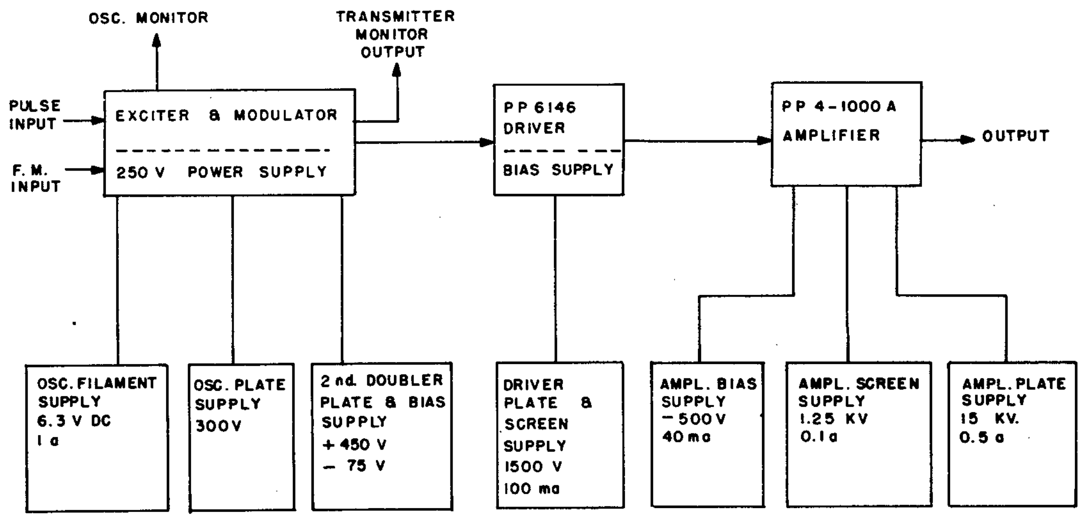

Fig. 16 - Complete transmitter

4-1000A tubes in the final amplifier. A number of independent power supplies are used as a matter of convenience. These are indicated along with their ratings.

Three views of the exciter are shown in Fig. 17. Figure 18 shows two views of the exciter mounted in a rack along with the associated power supplies, the monitors, and the pulse divider. The schematic of the intermediate output stage driver amplifier is given in Fig. 19 and the top view is shown in Fig. 20. Figures 21 and 22 are similar corresponding details for the final rf amplifier.

MONITOR AND INDICATING SYSTEMS

Transmitter monitoring circuits are provided, as shown by block diagram in Fig. 23, for measuring frequency against a known standard, observing the master oscillator pulse waveform, and observing the output frequency spectrum. The frequency monitor is a Millen one-inch oscilloscope operated as a Lissajou figure comparator. In detail, the transmitter exciter output is sampled by a single turn loop and compared by a Lissajou pattern with a 400 kc signal derived from a frequency standard. Prior to this, however, the sample is heterodyned to 400 kc with a signal which is also derived from the frequency standard. Amplifiers feeding the oscilloscope are of standard design and are noncritical.

The frequency spectrum monitor is a panoramic adapter model RCX tuned to accept the 400-kc output from the monitor receiver used in the frequency monitor equipment.

The pulse monitor is a one-inch Millen oscilloscope operated as a trigger scope with the vertical deflection plates coupled through an amplifier to the oscillator monitor point on the transmitter exciter. The horizontal sweep circuit is shown in Fig. 24. In this circuit a one-shot multivibrator generates a square wave, synchronized with the modulation pulse, which is fed to a charging tube to generate a linear sweep. As the duty factor limits brilliance, an intensity modulator is provided which operates from the square wave generator and feeds the control grid of the oscilloscope.

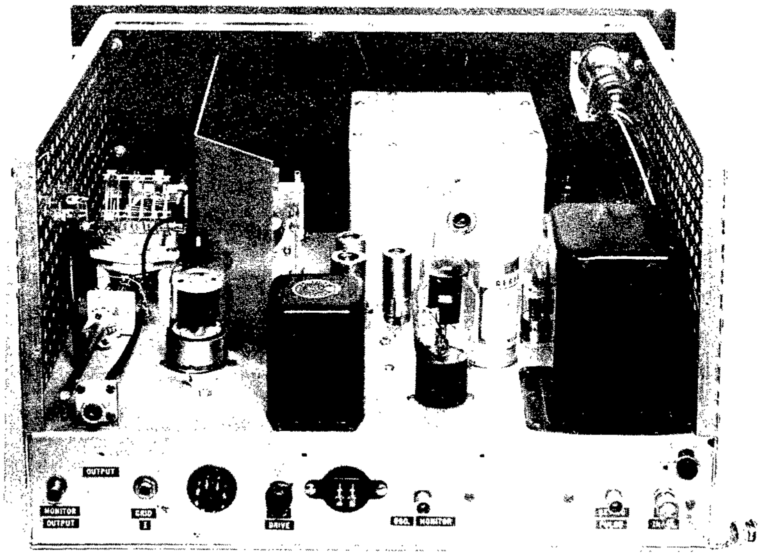

Fig. 17a - Exciter and modulator

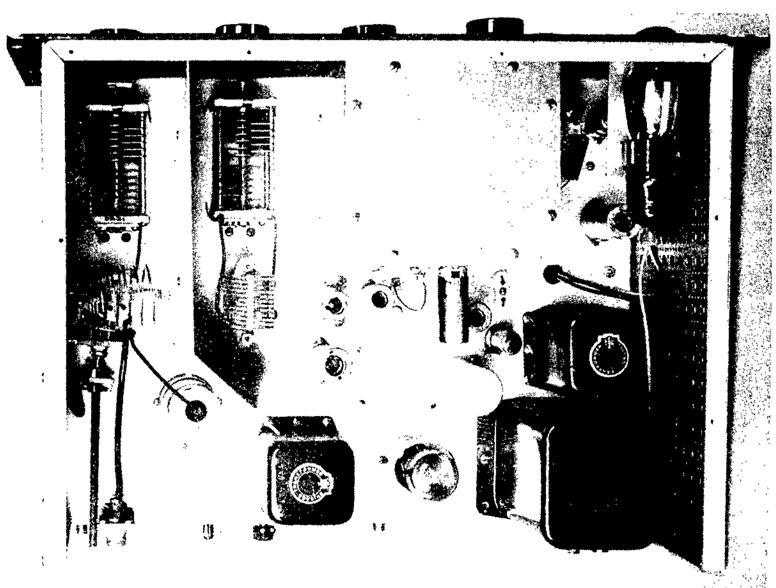

Fig. 17 b - Exciter and modulator

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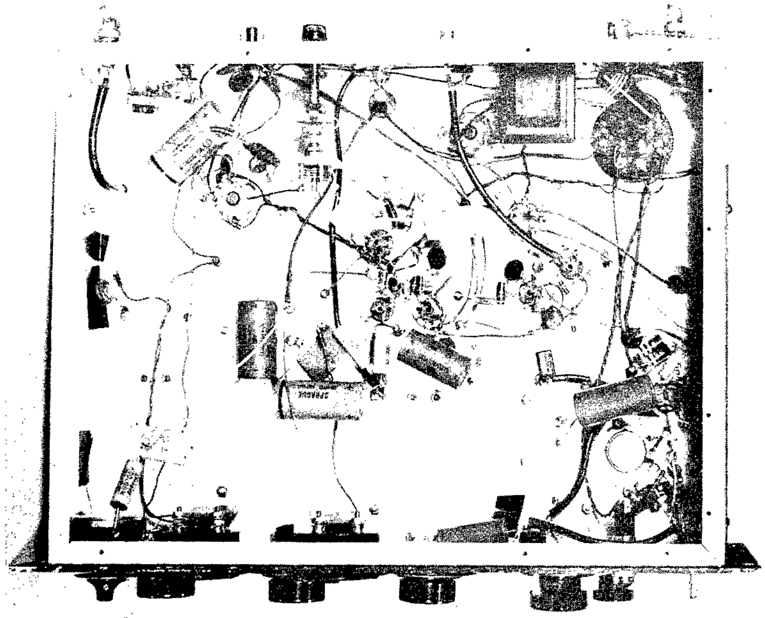
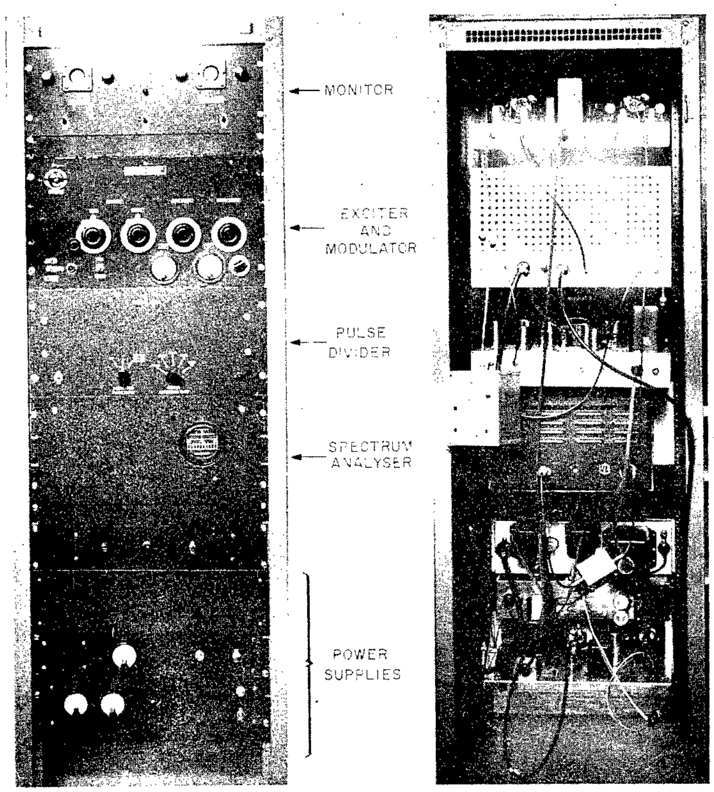


Fig. 17c - Exciter and modulator



(a) FRONT VIEW (b) REAR VIEW

Fig. 18 - Assembled exciter and associated equipment

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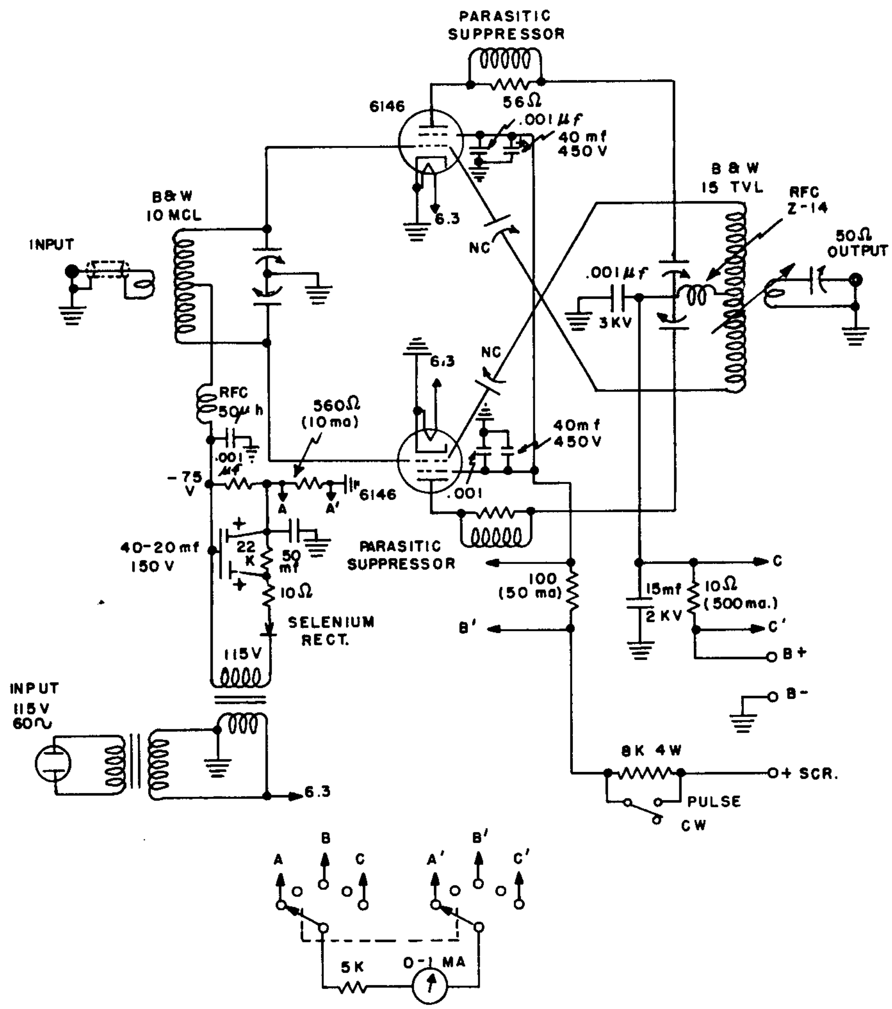

Fig. 19 - Intermediate rf driver amplifier

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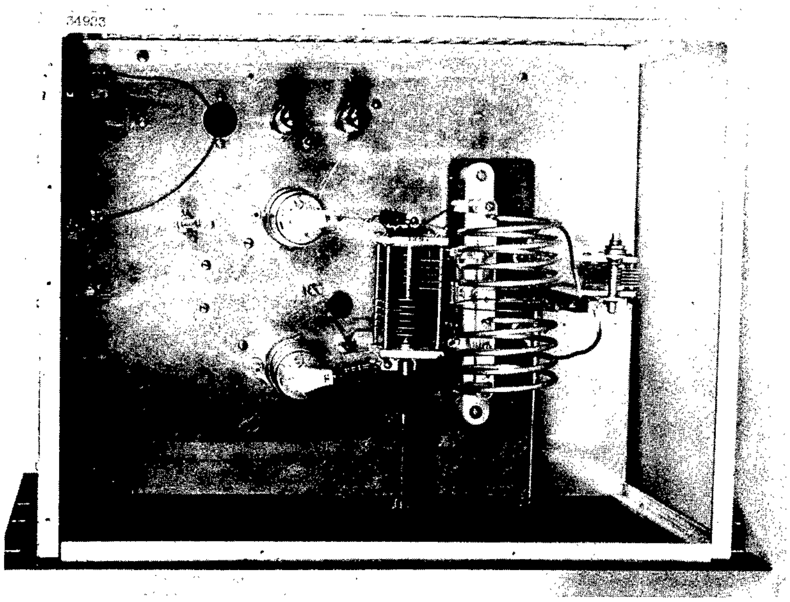

Fig. 20 - Top view of the intermediate rf amplifier

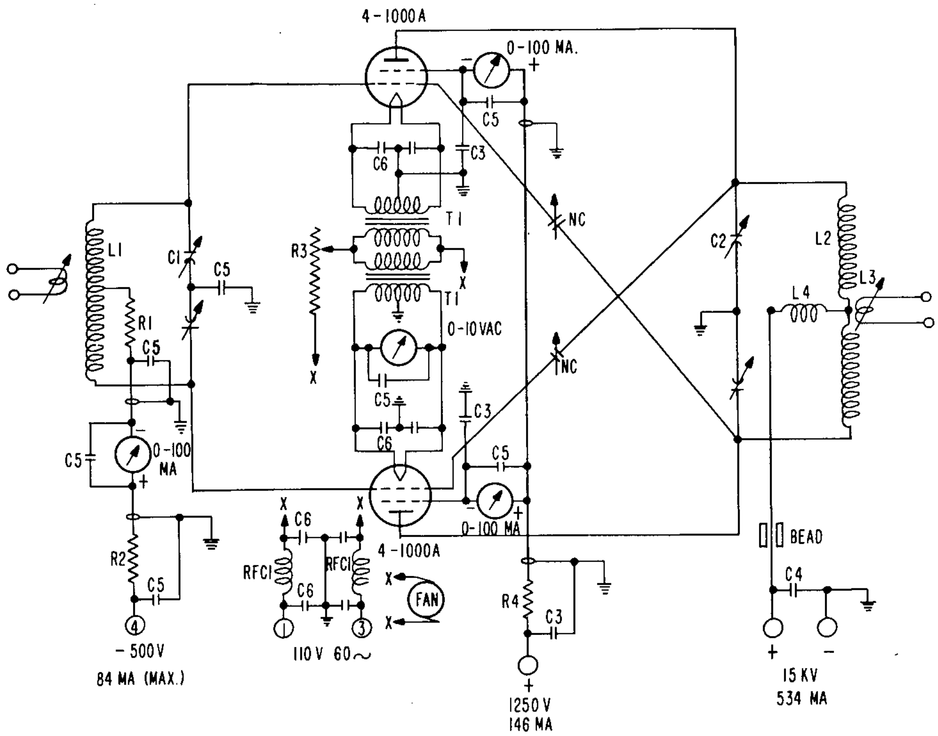

Fig. 21 - Final amplifier

C1 - Butterfly variable, 26 $\mu\mu$f per section, 0.030-in. spacing, Johnson 25LB15
C2 - Vacuum variable, 11 to 30 $\mu\mu$f, 30 kv per section, Jennings type SS-30
C3 - 0.001 μf, 3000 v disc ceramic
C4 - 500 $\mu\mu$f, 20 kv ceramic (TV type)
C5 - 0.001 μf, 600 v disc ceramic
C6 - 0.001 × 2 μf, 600 v disc ceramic
L1 - B&W 15 JVL (modify to 1 turn link)
L2 - 8 turns of 1/4-in. copper tubing, 3-1/2 in. diameter
L3 - 2 turns of No. 10 copper wire, 3-1/2 in. diameter
L4 - B&W miniductor No. 3002 in shield can
R1 - 100 ohm, 1 w carbon
R2 - 50 ohm, 1/2 w carbon
R3 - 6 ohm, 68 w (minimum) rheostat
R4 - 100 ohm, 3 w, noninductive (two 200 ohm, 2 w carbons in parallel)
RFC1 - Special for 3.4 amp
T1 - 7.5 v at 21 amp, Peerless F-3420-E or Chicago F-725
NC - Special neutralizing capacitor
FAN - 90 cubic feet per minute

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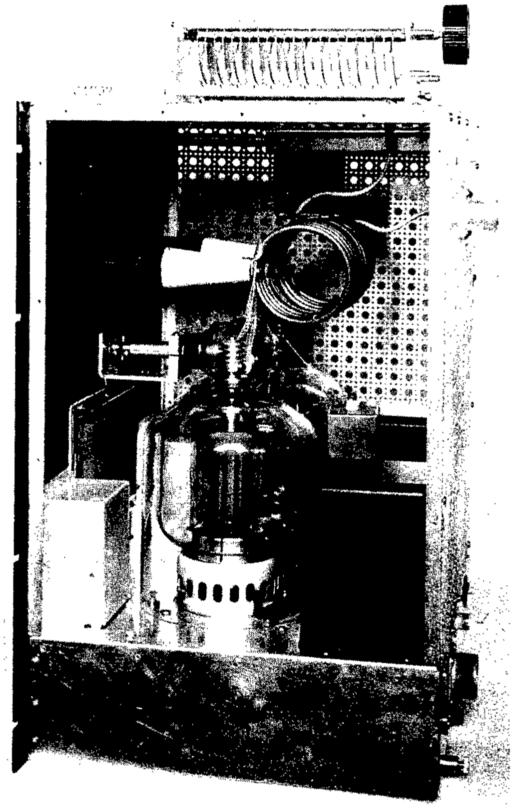

Fig. 22a - Final rf amplifier

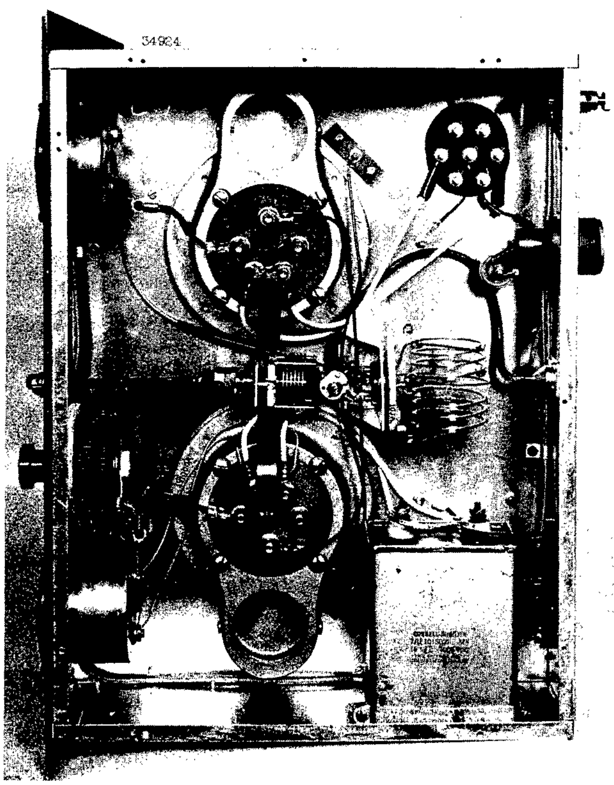

Fig. 22b - Final rf amplifier

[redacted]

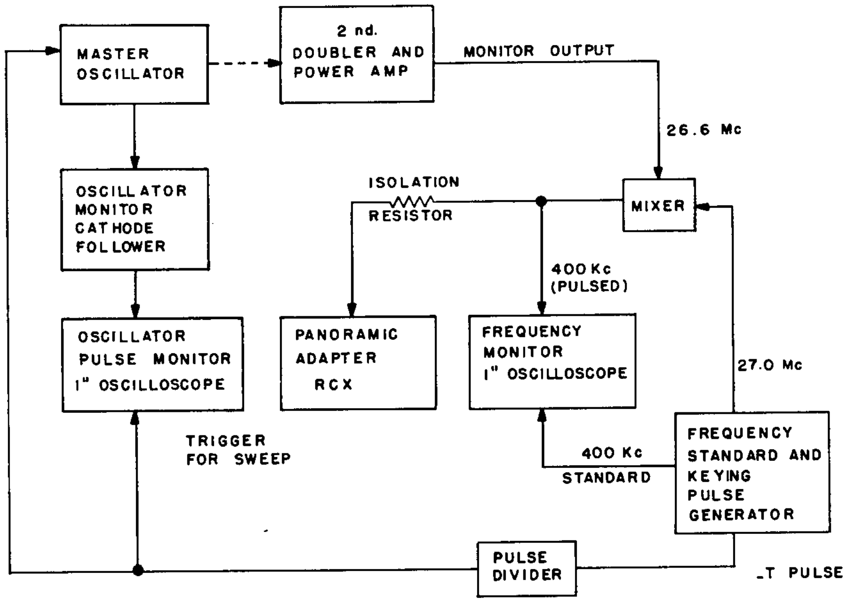

Fig. 23 - Transmitter monitors

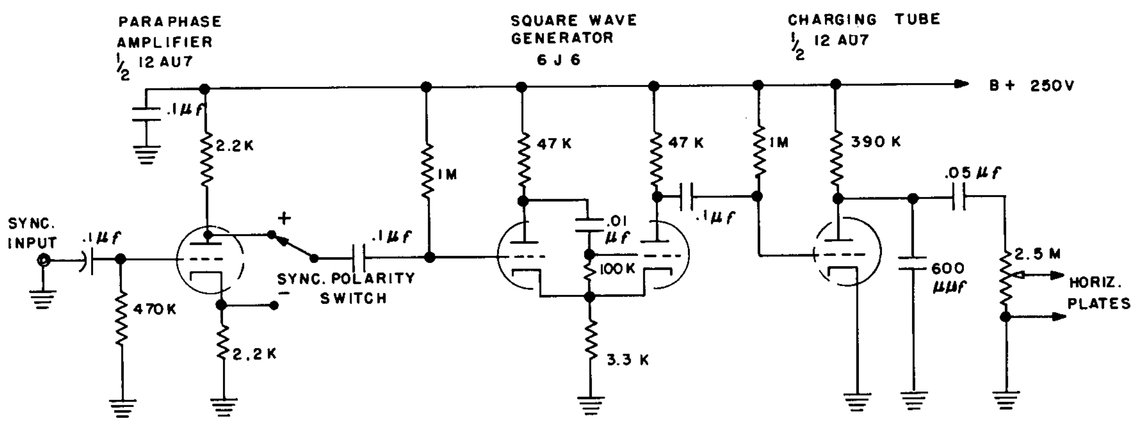

Fig. 24 - Horizontal sweep circuit of pulse monitor

CONCLUDING REMARKS

A research type radar transmitter has been described which is performing satisfactorily in an experimental cross-correlation, storage radar system. Certain refinements have been indicated which will be implemented when time permits or necessity requires. Other features of the complete radar system will be described in a series of subsequent reports.

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